

Compression Strength of Composite Primary Structural Components

Final Report – Summary of Research

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Performance Period: February 1, 1998 to January 18, 2000

NASA Grant NAG-1-2035

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June 1, 2000

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Introduction

The focus of research activities under NASA Grant NAG-1-2035 was the response and failure of thin-walled structural components. The research is applicable to the primary load carrying structure of flight vehicles, with particular emphasis on fuselage and wing structure.

Analyses and tests were performed that are applicable to the following structural components

- an aft pressure bulkhead, or a composite pressure dome,
- pressure cabin damage containment, and
- fuselage frames subject to crash-type loads.

Research Activities

Nonlinear Analysis of Composite Pressure Domes at Structural Discontinuities [1]¹

Continuum equilibrium equations are used to derive formulas for the interlaminar stresses, or through-the-thickness stresses, in a laminated composite shell. The derivation is developed in lines of curvature coordinates, includes geometric nonlinearity (small strains and moderate rotations) and a linear elastic, anisotropic material law. These interlaminar stress formulas require derivatives of the stress resultants and transverse shear resultants of shell theory to compute interlaminar stresses. Accurate derivatives of stress resultants is a stringent requirement on the numerical solutions to shell equations. Previously we solved the state vector equations governing the axisymmetric response of a shell of revolution by a multiple shooting method called stabilized march. Derivatives of the all the stress resultants are computed directly by this shooting method, so it appears that numerical solutions obtained stabilized marching are amenable to evaluation of the interlaminar stress formulas.

Crack Path Bifurcation at a Tear Strap in a Pressurized Shell [2]

Bifurcation of an initially longitudinal through-crack in an internally pressurized cylindrical shell at a circumferential stiffener is investigated using a finite element analysis. The finite element model is developed from a fracture test of an aluminum shell having a nine inch radius, a 0.040-inch wall thickness, and stiffened by two externally bonded circumferential straps spaced 16 inches apart. After initial stable crack growth in the longitudinal direction with increasing pressure, the crack propagated dynamically toward the strap, bifurcated near the strap into circumferential branches running parallel to the straps. Stable and unstable crack growth curves of pressure versus half-crack length are determined from the nonlinear analysis using a critical value of the crack tip opening angle as the criterion to predict crack advance. Although the crack growth curves are determined from a static analysis, they corroborate the test results for the location of crack path bifurcation. Also, the principal stress criterion for prediction of crack turning is consis-

1. Numbers in brackets refer to references listed under Grant Publications.

tent with the test.

Energy Absorption and Progressive Failure Response of Composite Fuselage Frames [3,4]

Semicircular Frames Fabricated from Gr/Ep Unidirectional Tape Vertical drop testing of transport aircraft fuselage sections indicate that the frames play a major role in the process of absorbing the impact energy in the crushing of the substructure below the main passenger deck. Subsequent static crush tests of scaled frames fabricated from graphite-epoxy tape show that they tend to absorb less energy than their aluminum counterparts due to the brittle-type failure modes of the composite compared to failure by ductile yielding of the aluminum. A mathematical model developed to optimize open section curved composite frames under static crush loading for improved energy absorption is used to design previously fabricated graphite-epoxy frames not optimized for energy absorption. Flanges were resized on three of these previously fabricated semicircular, I-section, frames. Static test results of the redesigned frames are compared to test results of the nominally equivalent original frames. The test results from the redesigned frames show an improved energy absorption relative to their original counterparts, and that the mathematical model predicts the correct sequence and location of failure events. However, the mathematical model did not predict the magnitudes of the force and displacement at the first major failure event that occurred in the test.

Tests of Braided Composite Fuselage Frames Under Radial Inward Load Two circular fuselage frame segments of forty-eight degrees, with an inside radius of 118 inches and a radial depth of 4.8 inches, are subjected to a radially inward, displacement in a universal testing machine. The cross section is in the shape of the letter *J*. The frames are made from 2X2 2D triaxial braided textile composite preforms of AS4 graphite yarns and PR 500 epoxy resin having an architecture of $[0^\circ_{18k}/\pm 64^\circ_{6k}]_{39.7\%}$ axial. Material coupons were cut from a third frame and tested in tension and flexure. Material property data from the coupon tests are compared to analytical predictions using the computer code TEXCAD. The measured responses in the two frame tests are the applied displacement, the corresponding force, and the strains. Sudden decreases in the force with quasi-static increasing displacement are correlated with the development of cracks and fractures in the frames observed during the test. A finite element analysis of the frame specimens is performed and the analysis compares well to the test results up to the first major failure event.

Grant Publications

Conference speaker indicated by boldface font.

- [1] **Steinbrink, S.E.**, and Johnson, E.R., “Nonlinear Analysis of Composite Pressure Domes at Structural Discontinuities,” *The 40th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Materials Conference and Exhibit*, (St. Louis, MO, April 12-15, 1999), American Institute of Aeronautics and Astronautics, Reston, VA, 1999, Volume 1, pp. 218-228 (AIAA Paper No. 99-1227).
- [2] **Cowan, Amy L.**, Carlos G. Dávila, Eric R. Johnson, and James H. Starnes, Jr., “Crack Path Bifurcation at a Tear Strap in a Pressurized Shell,” *The 41st AIAA/ASME/ASCE/AHS/A SC Structures, Structural Dynamics, and Materials Conference and Exhibit*, (Atlanta Georgia, April 3-6, 2000), Compact Disk, American Institute of Aeronautics and Astronautics, Reston, VA, 2000, (AIAA Paper No. 2000-1517).
- [3] **Pérez, J.G.**, Johnson, E.R., and Boitnott, R.L., “Design and Test of Semicircular Composite Frames Optimized for Crashworthiness,” *Proceedings of The 39th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Materials Conference*, (Long Beach, CA, April 20-23, 1998), American Institute of Aeronautics and Astronautics, Reston, VA, 1998, Part 1, pp. 27-38 (AIAA Paper No. 98-1703).
- [4] Pérez, José G., Richard L. Boitnott, and **Eric R. Johnson**, “Tests of Braided Composite Fuselage Frames Under Radial Inward Load,” *The 41st AIAA/ASME/ASCE/AHS/A SC Structures, Structural Dynamics, and Materials Conference and Exhibit*, (Atlanta Georgia, April 3-6, 2000), Compact Disk, American Institute of Aeronautics and Astronautics, Reston, VA, 2000, (AIAA Paper No. 2000-1547).

Students Supported by the Grant

- 1. Scott E. Steinbrink, Doctor of Philosophy in Engineering Mechanics, December 1998.
Dissertation Title: Geometrically Nonlinear Analysis of Axially Symmetric, Composite Pressure Domes Using the Method of Multiple Shooting
Initial Employer: Gannon University, Erie, Pennsylvania
Also supported in part under NASA Grants NAG -1-343 & NAG-1-537.
- 2. José G. Perez, Master of Science in Aerospace Engineering, July, 1999.
Thesis Title: Energy Absorption and Progressive Failure Response of Composite Fuselage Frames
Also supported in part under NASA Grants NAG -1-343 & NAG-1-537.
- 3. Amy L. Cowan, Master of Science in Aerospace Engineering, August, 1999.
Thesis Title: Crack Path Bifurcation at a Tear Strap in a Pressurized Stiffened Cylindrical Shell
Initial Employer: Naval Surface Warfare Center, Carderock Division
West Bethesda, Maryland.